10-10-00

A

*Multiple Rays of Multiple Interfering Received Signals

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PTO/SB/05 (4/98)
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10/06/00

UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 C.F.R. § 1.53(b))

Attorney Docket No.	1280.00271
First Inventor or Application Identifier	Paul W. Dent
Title	Method and Apparatus for Subtracting*
Express Mail Label No.	EM414006809US

JC927 U.S. PTO 09/680901 10/06/00

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: Assistant Commissioner for Patents
Box Patent Application
Washington, DC 20231

1. [X] * Fee Transmittal Form (e.g., PTO/SB/17) (Submit an original and a duplicate for fee processing)
2. [X] Specification [Total Pages 39] (preferred arrangement set forth below)
   - Descriptive title of the Invention
   - Cross References to Related Applications
   - Statement Regarding Fed sponsored R & D
   - Reference to Microfiche Appendix
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings (if filed)
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure
3. [X] Drawing(s) (35 U.S.C. 113) [Total Sheets 3]
4. Oath or Declaration [Total Pages 2]
   a. [X] Newly executed (original or copy)
   b. [ ] Copy from a prior application (37 C.F.R. § 1.63(d)) (for continuation/divisional with Box 16 completed)
      i. [ ] DELETION OF INVENTOR(S) Signed statement attached deleting inventor(s) named in the prior application, see 37 C.F.R. §§ 1.63(d)(2) and 1.33(b).

* NOTE FOR ITEMS 1 & 13: IN ORDER TO BE ENTITLED TO PAY SMALL ENTITY FEES, A SMALL ENTITY STATEMENT IS REQUIRED (37 C.F.R. § 1.27), EXCEPT IF ONE FILED IN A PRIOR APPLICATION IS RELIED UPON (37 C.F.R. § 1.28).

5. [ ] Microfiche Computer Program (Appendix)
6. Nucleotide and/or Amino Acid Sequence Submission (if applicable, all necessary)
   a. [ ] Computer Readable Copy
   b. [ ] Paper Copy (identical to computer copy)
   c. [ ] Statement verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

7. [ ] Assignment Papers (cover sheet & document(s))
8. [ ] 37 C.F.R.§3.73(b) Statement (when there is an assignee) [ ] Power of Attorney
9. [ ] English Translation Document (if applicable)
10. [ ] Information Disclosure Statement (IDS)/PTO-1449 [ ] Copies of IDS Citations
11. [ ] Preliminary Amendment
12. [X] Return Receipt Postcard (MPEP 503) (Should be specifically itemized)
13. [ ] * Small Entity Statement(s) (PTO/SB/09-12) [ ] Statement filed in prior application, Status still proper and desired
14. [ ] Certified Copy of Priority Document(s) (if foreign priority is claimed)
15. [ ] Other: ....

16. If a CONTINUING APPLICATION, check appropriate box, and supply the requisite information below and in a preliminary amendment:
[ ] Continuation [ ] Divisional [ ] Continuation-in-part (CIP) of prior application No: ______/______
Prior application information: Examiner ______ Group / Art Unit: ______
For CONTINUATION or DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 4b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

17. CORRESPONDENCE ADDRESS

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Signature	Dean A. Monco	Date	Oct. 6, 2000

FEE TRANSMITTAL for FY 2001

Patent fees are subject to annual revision

TOTAL AMOUNT OF PAYMENT ($) 1,748.00

Complete if Known	
Application Number	Unassigned
Filing Date	Herewith
First Named Inventor	Paul W. Dent
Examiner Name	
Group Art Unit	
Attorney Docket No.	1280.00271

METHOD OF PAYMENT

1. [X] The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

Deposit Account Number: 23-0785

Deposit Account Name: Wood, Phillips et al.

[X] Charge Any Additional Fee Required Under 37 CFR 1 16 and 1 17

[ ] Applicant claims small entity status See 37 CFR 1 27

2. [X] **Payment Enclosed:**

[X] Check [ ] Credit card [ ] Money Order [ ] Other

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	710	201	355	Utility filing fee	$710
106	320	206	160	Design filing fee	
107	490	207	245	Plant filing fee	
108	710	208	355	Reissue filing fee	
114	150	214	75	Provisional filing fee	

SUBTOTAL (1) ($)710.00

2. EXTRA CLAIM FEES

			Extra Claims		Fee from below		Fee Paid
Total Claims	51	-20** =	31	X	$18	=	$558
Independent Claims	9	- 3** =	6	X	$80	=	$480
Multiple Dependent					---	=	---

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	80	202	40	Independent claims in excess of 3
104	270	204	135	Multiple dependent claim, if not paid
109	80	209	40	** Reissue independent claims over original patent
110	18	210	9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($) 1,038

**or number previously paid, if greater: For Reissues, see above*

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for *ex parte* reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	390	216	195	Extension for reply within second month	
117	890	217	445	Extension for reply within third month	
118	1,390	218	695	Extension for reply within fourth month	
128	1,890	228	945	Extension for reply within fifth month	
119	310	219	155	Notice of Appeal	
120	310	220	155	Filing a brief in support of an appeal	
121	270	221	135	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive - unavoidable	
141	1,240	241	620	Petition to revive - unintentional	
142	1,240	242	620	Utility issue fee (or reissue)	
143	440	243	220	Design issue fee	
144	600	244	300	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	710	246	355	Filing a submission after final rejection (37 CFR § 1 129(a))	
149	710	249	355	For each additional invention to be examined (37 CFR § 1 129(b))	
179	710	279	355	Request for Continued Examination (RCE)	
169	900	169	900	Request for expedited examination of a design application	

Other fee (specify) ______________________________________

* Reduced by Basic Filing Fee Paid

SUBTOTAL (3) ($)

SUBMITTED BY				Complete (if applicable)	
Name (Print/Type)	Dean A. Monco	Registration No (Attorney/Agent)	30,091	Telephone	312.876-1800
Signature	Dean A. Monco			Date	Oct. 6, 2000

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APPLICATION FOR

UNITED STATES LETTERS PATENT

SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

Be it known that **PAUL W. DENT**, a citizen of Great Britain, residing at 637 Eagle Point Road, Pittsboro, in the County of Wake and State of NORTH CAROLINA has invented a new and useful **METHOD AND APPARATUS FOR SUBRACTING MULTIPLE RAYS OF MULTIPLE INTERFERING RECEIVED SIGNALS** of which the following is a specification.

CERTIFICATE OF MAILING BY "EXPRESS MAIL"

"Express Mail" Mailing Label Number EM414006809US

Date of Deposit: October 6, 2000

I hereby certify that this paper or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 35 CFR 1.10 on the date indicated above and is addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231.

Anne E. Regnier

Anne E. Regnier

PATENT
1280.00271
P12442-US1-RCUR

METHOD AND APPARATUS FOR SUBTRACTING MULTIPLE RAYS OF MULTIPLE INTERFERING RECEIVED SIGNALS

CROSS REFERENCE

This application is a Continuation-In-Part to U.S. patent Application no. 09/082,722, filed May 21, 1998; U.S. Patent Application no. 08/989,392, filed July 22, 1997; and U.S. patent Application no. 09/340,907, filed June 28, 1999, each to applicant, which are the parent applications for this application and form part of this application in their entirety.

BACKGROUND OF THE INVENTION

This invention relates to decoding of received signals and, more particularly, to decoding quantized and unquantized wanted data symbols from received signal samples.

The code-division multiple access (CDMA) mobile communications system known as IS95 transmits from a base station to different mobile terminals in its coverage area (the downlink) using different 64-bit orthogonal codes. Each such code is of the same length (64 bits) and carries voice or data traffic of approximately the same data rate. Variable-rate orthogonal coding is not used in that system.

A wideband CDMA system known as 3G (third generation) has been standardized in a cooperation between the European Telecommunications Standards Institute (ETSI) and NTT DoCoMo of Japan, and specifies variable-rate orthogonal coding in which signals of higher bitrate can use orthogonal codes of a shorter length to increase the frequency of data symbol transmission

while still remaining orthogonal to lower bitrate transmissions using longer orthogonal codes and a lower frequency of data symbol transmission. The shortest orthogonal code presently specified is 4 chips long and the longest is 256 chips long.

Also in IS95, transmissions from mobile terminals to base stations use orthogonal codes to code different data symbol groups from the same mobile terminal but do not use orthogonal codes to distinguish between different mobile terminals. Different mobile terminal transmissions (the uplink) are distinguished by the use of different non-orthogonal, pseudorandom codes.

U.S. patents nos. 5,151,919 entitled "CDMA Subtractive Demodulation" and 5,218,619 also entitled "CDMA Subtractive Demodulation" to Applicant describe a CDMA system using orthogonal codes in the manner of the above-described IS95 uplink, in which different signals are successively decoded and subtracted in order from strongest to weakest in order to eliminate interference of the stronger signals upon the weaker signals. The '919 and '619 patents are hereby incorporated by reference herein.

In U.S. patent no. 5,572,552 entitled "Method and system for demodulation of downlink CDMA signals", Dent and Bottomley describe an optimum receiver for receiving CDMA signals at a mobile terminal transmitted from a cellular base station that subtracts non-orthogonal multipath rays in a multipath channel equalizer when own-base interference is dominant. Such a "channel inverse" equalizer is disclosed to be non-optimum in the presence of other-base interference or thermal noise and a hybrid equalizer method is described that lies between the conventional RAKE equalizer method and the channel inverse equalizer method. The '552 patent is hereby incorporated

by reference herein.

In U.S. patent Application no. 09/082,722, filed May 21, 1998, entitled "Partially Block-interleaved CDMA Coding and Decoding" to Applicant, methods for transmitting and receiving orthogonally-coded CDMA signals are described such that signals retain their orthogonality for most transmitted data symbols under multipath conditions. The above application is hereby incorporated by reference herein.

In U.S. Patent Application no. 08/989,392, filed July 22, 1997, entitled "Orthogonal Block-Spreading Codes for the Multipath Environment", further methods are described for compensating for multi-user interference on the residual symbols not retaining their mutual orthogonality by virtue of the Block-interleaving method. This application is hereby incorporated by reference herein.

Also, in U.S. patent Application no. 09/340,907, filed June 28, 1999, entitled "Multi-Carrier Orthogonal Coding", methods are disclosed for transmitting and receiving CDMA signals that are orthogonally coded over more than one frequency channel. This application is hereby incorporated by reference herein.

This application further extends the methods of decoding orthogonal signals described in the parent applications to compensate for multipath propagation even when block-orthogonal coding is not used.

SUMMARY OF THE INVENTION

A Code Division Multiple Access system using orthogonal codes of variable length to reduce interference between transmissions to different receivers of different underlying information rates transmits a sum of all signals to a receiver, which processes the received signal to separate a signal of highest bitrate from the remaining signals to substantially eliminate interference from the lower bitrate signals to the highest bitrate signal. The receiver may continue to process the residual signal after subtracting the separated highest bitrate signal to decode at least one of the lower bitrate signals thereby substantially eliminating interference from the highest bitrate signal to the lower bitrate signals.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a series of waveforms illustrating a wanted signal and a plurality of interfering signals, and energy amounts produced by said signals;

Figure 2 is a block diagram of a receiver in accordance with the invention; and

Figure 3 illustrates superimposition of orthogonal spreading codes modulated with different data symbols in multi-code transmission.

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 illustrates an exemplary signal transmitted by a wireless base station employing orthogonal CDMA codes. In this example, a single, high-power, high datarate signal

employing a short (2-chip) repeated code "x,y", where x and y are spreading code values, overlaps transmission with a multiplicity of other, orthogonal signals employing longer codes that always comprise pairs of spreading code values "x,-y" in succession. For example, x and y could be binary1's giving a spreading code "11" and then x and -y in Boolean notation would be"10". Complex values "1,j" and "1,-j" are other examples of orthogonal chip pairs.

One implementation of the invention is described for the example where a high bit rate signal uses the spreading code "11" for successive transmitted symbols while lower bit rate signals use codes such as 10 01 01 10 , i.e. always a zero paired with a one in any chip pair corresponding to the chip pairs "11" of the high bit rate signal.

Assume the wanted symbols are So,S1,S2..... and are transmitted with spreading code 11, i.e. as S0 S0 S1 S1 S2 S2 S3 S3 etc. All of the other signals have spreading codes having 10 or 01 bit pairs following each other. If on the first chip of each pair the other signals with levels a,b,c... etc combine to give a+b-c-d ... etc, then on the second chip of each pair they have to give -(a+b-c-d....) i.e. the interfering waveform values due to the sum of all other signals are

W0 -W0 W1 -W1 W2 -W2 W3 -W3 .... etc

So the total transmitted signal waveform samples may be written as:-

S0+W0 S0-W0 S1+W1 S1-W1 S2+W2 S2-W2 ...... ETC

These are received through some multipath channel comprising a shortest path or ray of earliest time-of-arrival with amplitude and phase described by the complex number Co, and other multipath rays or echos with successive delays of 1 chip, 2 chips etc of amplitude and phase described by complex numbers C1,C2 etc.

It is possible to include a filter in the receiver ahead of all other processing which has the effect of ensuring that earlier paths or "taps"after applying such a pre-filter contain the most energy, and coefficients Co,C1,C2... now include the effect of the receive prefilter as well as the multipath propagation channel and any transmit filtering employed. The earlier paths communicate the latest symbols and the later paths are echoes of earlier symbols.

Received signal sample values Z0, Z1, Z2.... are thus described by:

$$Co(S0+W0) + C1(S_{-1} - W_{-1}) + \text{ earlier symbols } \ldots\ldots = Z0$$

$$C0(S0-W0) + C1(SO+W0) + \text{ earlier symbols } \ldots\ldots = Z1$$

Assume that the earlier symbols such as S_{-1} and interfering waveform values W_{-1} have already been separated from each other in a previous iteration, and the desire is now to separate So from Wo. Terms involving earlier values of S and W can thus be subtracted from both sides leaving modified values Zo', Z1'on the RHS, giving the 2x2 matrix equation:-

$$\begin{matrix} C0 & C0 \\ C1+C0 & C1-C0 \end{matrix} \quad x \quad \begin{matrix} S0 \\ W0 \end{matrix} \quad = \quad \begin{matrix} Z0' \\ Z1' \end{matrix}$$

Such equations can be solved so long as the determinant of the matrix does not approach zero, and the determinant of the above coefficient matrix is clearly the same as the determinant of the matrix

$$\begin{matrix} Co & Co \\ Co & -Co \end{matrix}$$

which is $-2Co^2$ and never zero or ill-conditioned, due to choosing the prefilter so that Co is as large as possible.

The equations can thus be solved for So and Wo, obtaining

$$So = (Zo'+Z1')/2Co \quad - \quad C1.Zo'/2Co^2$$

$$Wo = (Zo'-Z1')/2Co \quad + \quad C1.Zo'/2Co^2$$

and those values can be fed forward after quantizing So to a nearest symbol in the alphabet when resolving S1 and W1 from the next two signal samples.

One known method in which previously decoded symbols are fed forward to cancel intersymbol interference (ISI) when decoding future symbols is called Decision Feedback Equalization or DFE. Prior art DFE was concerned only with interference between symbols of a wanted symbol stream, and not with interference from unwanted signals. Moreover, in pure DFE according to the prior art all fed forward symbols were quantized or "decided" to nearest legal values in the symbol alphabet. In the above formulation however, it is seen that the values fed forward comprise a mixture

of quantized values like So which represent cancellation of ISI from one wanted symbol to the next and unquantized values like Wo which represent the sum of all other, unwanted signals.

Thus all other interferers emanating from the same base station transmitter are subtracted in one shot at the same time as the wanted signal is equalized for multipath propagation, when practicing the above method.

In DFE methods, the multipath ray that principally contributes to deciding the value of a data symbol is the ray with coefficient Co, while the rays with coefficients C1,C2 .... are treated as unwanted interference and subtracted.

In the alternative Viterbi Maximum Likelihood Sequence Estimator (MLSE), all rays are regarded as providing useful clues to a data symbol's value. One explanation of MLSE is that all possible decodings for the current symbol are retained along with a metric for each, indicative of the error between the unquantized value of So and each quantized value. Then the next symbol is decoded once for each of the retained assumptions being fed forward in turn, to obtain multiple decodings for the next symbol. Then, of all possible decodings for the next symbol S1 giving a particular value of S1,that having the lowest cumulative metric is retained, along with the value of So that was fed forward to obtain it. When this is repeated for each particular value of S1, a full set of possible retained S1 values is obtained, each with a cumulative metric and the associated history of fed forward symbols. It is also possible to use MLSE to hypothesize "future" symbols, such as S2 when decoding S1, as well as retaining all values of So to feed forward. It is then possible to decode a signal having passed through a channel for which Co is not the earliest significant ray, there being

an even earlier ray with coefficient C_{-1} that multiplies the "future" symbol. When hypothesizing two symbols to decode another, the number of retained results corresponds to all combinations of the last two symbols, and therefore the number of metrics is also greater. The collection of hypothesized symbols with their associated path histories and cumulative metrics form the Viterbi "States". The Viterbi MLSE algorithm is useful when no good receive prefilter can be found that makes Co the largest channel coefficient, and so long as the collection of states to deal with future symbol hypotheses does not become too numerous. When the MLSE algorithm is used with the current invention, there is not only a saved path history of decided symbols So,S1,S2..associated with each state but also a saved history of the associated unquantized values Wo,W1,W2..... etc.

When the above-described DFE or Viterbi interference cancelling decoder has operated to decode the high bit rate symbol stream So,S1,S2.... etc it will also thus have separated out a stream of unquantized values Wo,W1,W2.... etc which represent the sum of all the other signals, also compensated for multipath distortion. It is possible to save and then further process these unquantized values to decode any of the other signals contained therein, for example by despreading a signal using the rest of its orthogonal code (it was already despread by the first factor of 2) and now it will be found that the other signals are perfectly orthogonal, as the multipath has been compensated. Examination of how the multipath on the other signals has been compensated above will however reveal that it is equivalent to the use of the "inverse channel" filter mentioned in the above-incorporated '552 patent, which is not the optimum filter when other transmitter interference is significant. However, the saved samples Wo,W1,W2.... can be subjected to the inverse of the

"inverse channel" filter if desired, and then subjected to a different filter or indeed an iterative reapplication of the above procedure to decode a next lowest spreading factor signal from the others, and so forth. Thus one implementation of the invention can comprise successive decoding and subtraction of successively lower bit rate signals, the order of decoding in this method being in descending order of bit rate rather than in descending order of signal level, as in the incorporated references.

Figure 2 illustrates a receiver 10 to decode a highest bit rate CDMA signal while compensating for non-orthogonal multipath interference. The receiver 10 is adapted for use in a mobile communications system including a plurality of base stations and mobile terminals. Particularly, the receiver 10 represents either the mobile terminal or the base station used in a mobile communications system.

The present invention is described herein in the context of a mobile terminal. As used herein, the term "mobile terminal" may include a mobile communications radiotelephone with or without a multi-line display; a Personal Communications System (PCS) terminal that may combine a mobile communications radiotelephone with data processing, facsimile and data communications capabilities; a PDA that can include a radiotelephone, pager, Internet/intranet access, Web browser, organizer, calendar and/or a global positioning system (GPS) receiver; and a conventional laptop and/or palmtop receiver or other appliance that includes a radiotelephone transceiver. Mobile terminals may also be referred to as "pervasive computing" devices.

The receiver 10 includes an antenna 12 that receives radio signals which are then

filtered and amplified in a block 14 to select a desired frequency channel. The selected signals are analog-to-digitally converted to representative digital samples in an A to D convertor 16 which can operate according to any conventional or known method. The digital samples are processed in an Initial Channel Estimator 18 to determine an initial channel estimate including the above-named channel coefficients Co,C1.. etc. The initial channel estimates are so called because they are subsequently modified when the prefilter is calculated in a prefilter calculation block 20, and also because values based on initial channel estimates, which are usually made using only known symbols inserted into the signal by the transmitter, can be refined later by using unknown symbols as now-known symbols after they have been decoded, a process known as channel tracking.

The initial channel estimates are used to determine, in the prefilter calculation block 20, the coefficients of a prefilter 22 through which the digital signal samples from the A to D converter 16 are passed in order to change the initial channel to a modified channel in which most of the wanted signal energy appears in an earliest ray and a minimum amount of wanted signal energy appears in rays earlier than that, i.e. minimum dependence on "future" symbols, only dependence on "past" symbols. The new channel estimates after the signal has been filtered by the prefilter 22 are also calculated in the prefilter calculation block 20 and passed with the prefiltered signal samples to a subtract block 24. If the A to D convertor 16 oversamples the signal at more than one sample per symbol, prefiltering can also comprise selecting or computing only one sample per symbol as the prefilter output, the selected or computed output sample having the above-described property of maximum energy in the earliest ray, i.e. the modified channel coefficient Co is preferably larger than

C1, C2 etc and coefficients C_{-1} and earlier are preferably smaller.

At the subtract block 24, the above equations are used to subtract the influence of an earlier-determined symbol Si and an earlier-determined interference waveform value Wi. In a quantize block 26, the signal, with the influence of earlier symbols and interference now subtracted is separated into a quantized symbol S(i+1) and a new waveform point W(i+1). The value of W(i+1) obtained by the above solution of two simultaneous equations for the unquantized symbol value S and W may optionally be modified by plugging back into the equations the quantized value of S(i+1) to obtain a new value of W(i+1) that now depends to which symbol value S(i+1) was quantized. When a Viterbi (MSLE) algorithm is used to retain multiple possible quantizations of S(i+1), there will thus be corresponding multiple values of W(i+1). These multiple W-values may be obtained by plugging the quantized value of S into the two equations and solving them now in a least squares sense for the single remaining unknown W.

The determined S(i+1) and W(i+1) values are then fed back (decision feedback) via a delay block 28 to the subtract block 24 to subtract their influence on the next two signal samples to be decoded, and the stream Si, S(i+1) is output. The unquantized values of S may alternatively be output as "soft information" to an error correction decoder, such as a convolutional decoder. If the symbols S are binary (BPSK) bits or quaternary (QPSK) bit pairs, relating the soft output values to bit likelihood values required by the error-correction decoder is trivial. If higher order constellations such as 16QAM (quadrature amplitude modulation) or 8-PSK (phase shift keying) are used, then these M-ary symbol soft values may have to be converted to bitwise soft information,

which however can be done according to the method of U.S. patent application no. ...., filed Feb. 8, 2000, entitled "Methods and Systems for Decoding Symbols by Combining Matched-Filtered Samples with Hard Symbol Decisions" which is hereby incorporated by reference herein. When more than one previously decoded symbol value and interference waveform affects the next two signal samples, the symbol and waveform values are passed through an FIR filter comprising the channel coefficients of the delayed rays C1,C2,C3 etc to determine the values that shall be subtracted, thus collecting together their contributions that are simply denoted in the above equations by " + earlier symbols".

When a Viterbi MLSE algorithm is used, such an FIR filtering and interference subtraction may be performed "per state", using the symbol and interference waveform history associated with each state, also known as "per survivor processing".

The above description was simplified to assist understanding by considering only a high bit rate signal using a 2-chip spreading code while all other signals used longer orthogonal codes. If another signal had also used an orthogonal 2-chip code, then there could only be one other interfering signal as there are only two, 2-chip orthogonal codes. The method may then advantageously be converted to a joint demodulation method to demodulate both signals at the same time, by quantizing both S and W values, the quantized W-values then representing the other signal's symbols. Joint demodulation of two overlapping signals is known in the art, as is joint demodulation of multiple overlapping signals. Where the current invention differs however, is that only the sum of multiple interfering signals need be determined as the waveform samples W, and not their individual

symbols. Thus there is a considerable reduction in complexity when practicing this invention for interference cancellation.

The invention may however be extended to include the case where the high bit rate signal uses one or more orthogonal codes longer than 2 bits. For example, the wanted signal may use the 4-chip code 1010 repeated, while other signals use codes composed of the groups 1111,1100 and 1001. The wanted signal may also comprise a symbol stream using one of the above four codes plus a symbol stream using another of the codes, both of which are to be separated from each other and from the other interferers. Before describing this extension of the invention however, another generalization is discussed. A high bit rate signal using the 2-chip spreading code 11 (repeated) will be found to have a spectrum largely confined to the central part of the frequency channel, while other signals using codes composed of repeated 10 or 01 pairs have spectra largely confined to the outer parts of the channel, or vice-versa. Alternatively, a signal using complex 2-chip spreading code (1,j) as opposed to the orthogonal (1,-j) would be found to be confined to the upper as opposed to the lower part of the frequency channel. To avoid particular signals being restricted to only certain parts of the spectrum, resembling frequency-division multiple access (FDMA), assignment of codes to signals can be permuted from symbol to symbol thereby achieving "spectral hopping" which causes each signal to cover the whole channel spectrum in the mean. Spectral hopping is different from "frequency hopping" in that the latter comprises hopping between single sub-bands or channels, while the former comprises hopping between different spectral shapes that are not necessarily restricted to a single sub-band. Another method of ensuring that every signal covers the entire spectrum is to

apply a pseudorandom sequence of complex rotations to each chip, the same rotation being applied to all signals alike so as not to disturb their mutual orthogonality. When decoding the signal as above, the known phase rotations applied to the signals must be accounted for when solving the above equations and when subtracting the influence of earlier-decoded values. This may be done by including the pseudorandom rotation with the channel coefficients used at each iteration, as a phase rotation applied at the transmitter is effectively part of the channel phase through which a symbol propagates.

Received signal sample values Z0, Z1, Z2.... are then described by:

$$A1.Co(S0+W0) + Ao.C1(S_{-1} - W_{-1}) + \text{ earlier symbols } \ldots\ldots = Z0$$

$$A2.C0(S0-W0) + A1.C1(SO+W0) + \text{ earlier symbols } \ldots\ldots = Z1$$

As before, terms involving earlier values of S and W can be subtracted from both sides leaving modified values Zo', Z1'on the RHS, giving the 2x2 matrix equation:-

$$\begin{matrix} A1.C0 & A1.C0 \\ A2.C0+A1.C1 & A1.C1-A2.C0 \end{matrix} \times \begin{matrix} S0 \\ W0 \end{matrix} = \begin{matrix} Z0' \\ Z1' \end{matrix}$$

where Ao,A1,A2... etc is the sequence of complex chip rotations, i.e. the A-values are of amplitude unity and pseudorandom phase.

The first equation can be "derotated" by A1* and the second by A2* leaving:

$$\begin{bmatrix} Co & Co \\ Co + A2^{*}A1.C & -Co + A2^{*}A1.C1 \end{bmatrix} \times \begin{bmatrix} So \\ W0' \end{bmatrix} = \begin{bmatrix} A1^{*}.Z0' \\ A2^{*}.Z1' \end{bmatrix}$$

This is the same equation as before but with Z0', Z1' and C1 replaced by phase-rotated versions of those quantities due to the A-factors. Consequently, the equations can be solved in the same way as previously described by use of the known complex spreading sequence given by the A-values to modify the phase angles of the C1, Z0' and Z1' values, giving

$$So = (A1^{*}.Zo'+A2^{*}.Z1')/2Co \quad - \quad A2^{*}A1.C1.A1^{*}.Zo'/2Co^{2}$$

$$Wo = (A1^{*}.Zo'-A2^{*}.Z1')/2Co \quad + \quad A2^{*}A1.C1.A1^{*}.Zo'/2Co^{2}$$

or

$$So = (A1^{*}.Zo'+A2^{*}.Z1')/2Co \quad - \quad A2^{*}.C1.Zo'/2Co^{2}$$

$$Wo = (A1^{*}.Zo'-A2^{*}.Z1')/2Co \quad + \quad A2^{*}.C1.Zo'/2Co^{2}$$

The first term of the solution is just the "despread value" which is produced by correlating the received signal samples with the conjugate of the complex spreading sequence while the second term represents subtraction of multipath interference. It is acceptable to subtract multipath interference so long as the prefilter has modified the channel to ensure that Co is the dominant channel coefficient

containing the majority of the wanted signal energy.

One type of prefilter that ensures that all the wanted signal energy appears in a single channel coefficient is the time-reverse conjugate filter. This is an FIR filter with coefficients $C_2{}^*, C_1{}^*, Co, C^*_{-1}, C^*_{-2}$ when the channel coefficients are $C_{-2}, C_{-1}, Co, C_1, C_2$.

Convolving the channel with the time-reversed conjugate channel yields a modified channel coefficients:

$C_2{}^*\ C_{-2}$

$C_2{}^*\ C_{-1} + C_1{}^*\ C_{-2}$

$C_2{}^*Co + C_1{}^*\ C_{-1} + Co^*\ C_{-2}$

$C_2{}^*\ C_1 + C_1{}^*Co + Co^*\ C_{-1} + C^*_{-1}\ C_{-2}$

$|C2|^2 + |C_1|^2 + |Co|^2 + |C_{-1}| + |C_{-2}|^2$

$C_1{}^*C_2 + Co^*C_1 + C_{-1}{}^*\ Co + C_{-2}{}^*\ C_{-1}$

$Co^*C_2 + C_{-1}{}^*C_1 + C_{-2}{}^*Co$

$C_{-1}{}^*C_2 + C_{-2}{}^*C_1$

$C_{-2}{}^*C_2$

It can be seen that the modified channel has a Hermitian symmetry about a center coefficient which is just the sum of the powers in all the multipath rays. If the effect of all the other rays could simply be subtracted therefore, and data decoded using only the center term, the performance would be as

good as the total signal power in all rays, which is the best possible performance.

It has already been described how rays of positive delay can be subtracted by using already decoded symbols and interference waveform values. However, the above Hermitian-symmetric channel has rays of negative delay relative to the main ray, which require as yet undecoded symbols to subtract their effect. The Viterbi algorithm can be used to postulate all possible combinations of future symbols, so long as these are not too numerous, and to decode the present symbol for each postulate. When the next symbol is decoded, the previous decodings are pruned to only those that were made for that value of the next symbol, and so forth. The number of states needed for the Viterbi approach may be reasonable for binary symbols, but explodes if the data symbols are from a larger alphabet such as quaternary, 8-PSK, 16QAM or the like. Thus an alternative approach is needed when the symbol alphabet is large.

Figure 1 illustrates a wanted signal 50 with a 2:1 spreading, which consumes the code space of two 4:1 spread signals, plus a first interfering signal 52 spread 4:1, now occupying the code space of three out of four 4:1 spread signals, and the remaining 1/4 of the 4:1 code space is occupied by second and third 8:1 spread interfering signals 54 and 56.

An alternative however might be a pair of 4:1 spread wanted signals, each carrying half the data symbol rate, which occupies an equivalent amount of code space to a 2:1 spread signal. Yet another alternative would be eight 16:1 spread signals, each carrying 1/8th the data symbol rate, with the other half of the code space occupied by unspecified but orthogonal interferers. In this latter case, each wanted symbol is eight times as long in time duration as in the 2:1 spreading example. As

a result, many more of the delayed rays of 1,2,3,4 etc chips delay comprise multipath interference that is largely within the duration of the same group of wanted data symbols. This can be exploited to alleviate the need for a complex Viterbi algorithm for compensating the rays of negative delay.

Figure 3 illustrates an exemplary case of such multi-code transmission. Each square of figure 3 represents the superimposition of N, N-chip orthogonal codes, each modulated with a different data symbol. Thus each of the N different symbols is constant for the duration of one square, but is modulated by the N chips of an orthogonal code with a chip duration of 1/Nth of a square. A square containing N such symbols of information is received through a multipath channel, preferably prefiltered as described above so that there is a dominant ray or path with channel coefficient Co. Other delayed rays have channel coefficients C1,C2 etc while rays of shorter delay than the main ray have channel coefficients C_{-1},C_{-2} etc. The symbols in successive squares are the sets labeled S_{i-1}, S_i, S_{i+1} etc. To decode the symbols in a square, the signal is sampled N times yielding complex samples Zo,Z1.....Z(N-1). The sample position for Zo is indicated by the heavy vertical dashed line, and the squares through which it passes indicate which rays and symbols contribute to the sample value. It can be seen that Zo depends on the current symbol set S_i through the main channel Co and on the current symbol set advanced by 1,2 and 3 chips through the channel coefficients C_{-1}, C_{-2}, C_{-3} as well as the previous symbol set S_{i-1} delayed by one, two and three chips and weighted by the channel coefficients C_1, C_2, C_3 respectively.

The next sample, Z1, will depend on the current symbol set Si through channels C_1,Co,C_{-1}, and C_{-2} , the previous symbol S_{i-1} through channel coefficients C2 and C3, and the future

symbol set S_{i+1} through channel coefficient C_{-3}. Successive samples will depend less on past symbol set S_{i-1} and more on future symbol set S_{i+1}. The above is entirely expressed by the matrix equations

$$Zi = A.\ S_{i-1} + B.\ Si + C.\ S_{i+1}$$

where Zi is the sample vector (Zo....Z(N-1)) for square "i", the S-values are vectors of the corresponding symbol sets, and A,B and C are square matrices, the elements of which are combinations of the channel coefficients with signs given by the orthogonal code values. This equation can be rearranged to give the solution for Si as

$$Si = B^{-1} Z_i - B^{-1} A.\ S_{i-1} - B^{-1}C.\ S_{i+1}$$

Assuming the past symbol set has been decoded, but the future symbol set has not, an approximation for Si can be obtained by setting the future symbol set S_{i+1} to zero. The symbols of Si may then be quantized to the nearest values in the alphabet for feeding forward when S_{i+1}> is decoded. The unquantized values may be converted to bitwise soft information for feeding to an error-correction decoder. If desired, after a similar approximation has been obtained for S_{i+1}, it can be fed back to improve the decoding of Si. Alternatively, the similar expressions for future symbols, can be back-substituted algebraically to obtain an expression for Si of the form

$$Si = Uo.Zi + U1.Z_{i+1} + U2.Z_{i+2} \ldots\ldots -V.S_{i-1}$$

where the successive matrices U1, U2 are hopefully diminishing to zero after a few terms. These matrices are constant so long as the channel coefficients and the orthogonal codes are constant, and may be precomputed in this case.

When the orthogonal codes are Fourier sequences, each "square" of figure 3 is transmitting its symbol set using different sub-carriers of an Orthogonal Frequency Division Multiplex (OFDM) system. When the orthogonal codes are Walsh codes however, which have been termed "sequencies" in analogy with the "frequencies" which characterize Fourier sequences, the modulation may be termed Orthogonal Sequency Division Multiplex (OSDM). As the number of chips in the code or square is increased along with the corresponding size of the symbol sets Si, i.e. as the order of the OSDM is increased, the channel delay spread is more and more confined to the limits of one square in duration, with Inter-square Interference occurring only for the chips at the edges of the square. Moreover, only the chips at the trailing edge are affected by future symbol sets, which have to be assumed to be zero to obtain the simple approximate solution derived above. Therefore the approximation will improve with increasing order of OSDM and for an expected maximum amount of delay spread in a given application, such as wireless data networks, there will be an appropriate order of OSDM that permits the approximate solution to perform adequately.

Other aspects of a complete receiver such as channel tracking may be derived from known prior art methods. For example, an initial estimate of the channel coefficients Ci may be made

using known symbols transmitted by the transmitter, and then refined after decoding data symbol sets by using them as extensions of the known symbols. One or more symbols of a symbol set may be periodically set to a known value by the transmitter to assist channel tracking. One symbol in every symbol set can even be set equal to a known symbol, as with high order OSDM, that only consumes 1/Nth of the channel capacity. Moreover, when one or more of the symbols in a square is known a-priori, the equations for the unknown symbols become over dimensioned and can be advantageously solved in a least-squares sense.

In the above derivation of an OSDM receiver it was assumed that all the orthogonal codes were carrying symbols to be decoded. If it is desired to omit decoding some symbols of a set and to decode a subset of n symbols of the set only, where n < N, then the size of the above matrices may be reduced from N x N to N x (n+1), the first n rows corresponding to symbols desired to be decoded and quantized, and the (n+1)'th row corresponding to an interfering waveform which is the sum of the remaining symbols not desired to be decoded, and moreover not therefore quantized when fed forward to subtract delayed ISI when decoding the next symbol. This represents the generalization of the 2 x 2 case used in introducing the invention, which, in its interference-cancellation mode, comprises Decision Feedback of previously decoded values some of which are quantized and some of which are not quantized, thereby achieving the subtraction of multiple interferers in a single step.

As has been shown in U.S. patent no. 5,937,015 to Dent and Bottomley, entitled "Interference Mitigation by Joint Decoding of Overlapped Signals", error correction coding may be

employed to improve the reliability of already-decoded symbols that are used in decoding further symbols, with appropriate choice of interleaving pattern. The interleaving pattern determines the order in which bits from a receiver such as disclosed in this invention are fed to the error correction decoder. The preferred interleaving order is to select soft-bits from the just-decoded symbol set to feed to the error correction decoder followed by soft-bits that remain from previously decoded symbol sets. That allows the latter, now assumed to be more reliable bits, to flush through the bits from the just-decoded symbol thereby improving the reliability of bits from the just decoded symbol. These will be used to flush through soft bits from the next-decoded symbol, and so on. The '015 patent is hereby incorporated by reference herein together with its parent, U.S. patent no. 5,673,291 entitled "Simultaneous Demodulation and Decoding of a Digitally Modulated Radio Signal using Known Symbols"

The present invention has been described with respect to a block diagram for a receiver, illustratively in a mobile terminal or a base station. It will be understood that each block of the block diagram can be implemented by computer program instructions. These program instructions may be provided to a processor to produce a machine, such that the instructions which execute on the processor create means for implementing the functions specified in the blocks. The computer program instructions may be executed by a processor to cause a series of operational steps to be performed by the processor to produce a computer implemented process such that the instructions which execute on the processor provide steps for implementing the functions specified in the blocks. Accordingly, the illustrations support combinations of means for performing a specified

function and combinations of steps for performing the specified functions. It will also be understood that each block and combination of blocks can be implemented by special purpose hardware-based systems which perform the specified functions or steps, or combinations of special purpose hardware and computer instructions.

A person skilled in the art may make numerous modifications or adaptations to receivers and transmitters based on the above teachings and those of the incorporated disclosures, while remaining within the scope and spirit of this invention as described by the attached claims.

CLAIMS

I claim:

1. A method of decoding quantized and unquantized wanted data symbols from received signal samples, comprising:

processing a group of currently received signal samples to determine a corresponding current set of unquantized wanted data symbols and an interfering waveform representative of a sum of other unwanted data symbols by subtracting an amount of a previously decoded set of quantized wanted symbols and a previously determined interfering waveform; and

quantizing said determined current set of unquantized wanted symbols to obtain corresponding quantized symbols.

2. The method of claim 1 wherein processing a group of currently received signal samples further comprises determining a set of channel coefficients characterizing multipath propagation.

3. The method of claim 2 wherein processing a group of currently received signal samples further comprises filtering said received signal samples using a filter based on said channel coefficients.

4. The method of claim 3 wherein said filter comprises a time-reversed conjugate channel filter.

5. The method of claim 1 wherein said current set of unquantized wanted symbols includes only one wanted symbol.

6. The method of claim 5 wherein processing a group of currently received signal samples comprises combining a pair of successively received signal samples in a first combining way to obtain said current unquantized symbol and combining the same pair of samples in a second combining way to obtain a value of said interfering waveform.

7. The method of claim 6 wherein said first and second combining ways are orthogonal combining ways.

8. The method of claim 6 wherein said first and second combining ways comprise multiplying said received signal sample pairs by a conjugate of a pair of complex spreading code values.

9. The method of claim 2 wherein said channel coefficients are determined by correlating said received signal samples with known ones of said data symbols.

10. The method of claim 9 wherein said known symbols are known by both a transmitter and a receiver.

11. The method of claim 9 wherein said known symbols include previously decoded symbols.

12. The method of claim 11wherein said known symbols include previously decoded symbols and using an error correction decoder.

13. The method of claim 1 further comprising:

hypothesizing a set of said quantized wanted symbols not yet decoded;

subtracting interference caused by said not yet decoded wanted symbols from said signal samples; and

using a Viterbi Maximum Likelihood Sequence Estimator to determine a sequence of hypothesized quantized data symbols having a smallest measure of quantizing error between the unquantized symbols and the quantized symbols.

14. A method of decoding Orthogonal Sequency Division Multiplexed symbols from signal samples received through a multipath channel, comprising:

filtering the received signal samples using a filter based on multipath channel coefficients;

grouping the filtered signal samples into vectors of N signal samples;

computing a first and a second N x N complex matrix based on multipath channel coefficients and a set of orthogonal codes used for said Orthogonal Sequency Division Multiplexed symbols;

multiplying a previously decoded and quantized set of symbols by said second matrix and combining it with a product of said first matrix with a current group of N filtered signal samples to obtain a current set of unquantized decoded symbols; and

quantizing said current set of unquantized symbols to obtain a current decoded and quantized set of symbols.

15. The method of claim 14 wherein said previously decoded and quantized set of symbols are further processed using an error correction decoder to improve decoding reliability.

16. The method of claim 15 wherein said previously decoded and quantized set of symbols are the result of processing the corresponding set of unquantized symbols using an error correction decoder.

17. A method of decoding Orthogonal Sequency Division Multiplexed symbols from signal samples received through a multipath channel, comprising:

prefiltering the received signal samples using a prefilter based on multipath channel coefficients;

grouping the prefiltered signal samples into vectors of N signal samples;

computing a series of N x N complex matrices including at least a first and a second matrix and a final matrix based on said multipath channel coefficients and a set of orthogonal codes used for said Orthogonal Sequency Division Multiplexed symbols;

multiplying a current one of said N-sample vectors by a corresponding one of said at least first and second matrices and sample vectors received successively later in time by successive ones of said matrices and combining the products and further combining with the product of a previously decoded and quantized set of symbols by said final matrix to obtain a current set of unquantized decoded symbols; and

quantizing said current set of unquantized symbols to obtain a current decoded and quantized set of symbols.

18. The method of claim 17 wherein said previously decoded and quantized set of symbols are further processed using an error correction decoder to improve decoding reliability.

19. The method of claim 18 wherein said previously decoded and quantized set of symbols are the result of processing the corresponding set of unquantized symbols using an error correction decoder.

20. A method of decoding overlapping signals of successively lower datarate comprising:

decoding signals of a highest datarate first and producing a residual waveform corresponding to a sum of all signals of lower datarate;

decoding signals of a next successively lower datarate by reprocessing said residual waveform and producing an updated residual waveform corresponding to a sum of all remaining signals of lower datarate than the signals of the next successively lower datarate; and

repeating decoding signals of a next successively lower datarate by reprocessing said residual waveform and producing an updated residual waveform corresponding to a sum of all remaining signals of lower datarate than the signals of the next successively lower datarate, until all desired signals are decoded.

21. The method of claim 20 wherein decoding signals of a highest datarate comprises compensating for interference from signals of a lower datarate.

22. The method of claim 20 wherein decoding of signals comprises compensating for Intersymbol Interference due to multipath propagation.

23. A method for decoding overlapping data symbols modulated with mutually orthogonal spreading codes in which some of said symbols are known a-priori, comprising:

receiving blocks of signal samples through a channel suffering from multipath propagation, a number of signal samples in a block being equal to a length of said orthogonal spreading codes;

subtracting from said signal samples intersymbol interference (ISI) related to previously decoded symbols and to said known symbols to produce corresponding blocks of ISI-compensated signal samples; and

processing said ISI-compensated sample blocks to obtain a least-squares solution for the remaining, unknown data symbols each quantized to a nearest symbol in the alphabet of symbols with minimum mean-square quantizing error.

24. The method of claim 23 wherein said subtracted intersymbol interference is based on channel coefficients that describe said multipath propagation.

25. The method of claim 24 wherein said channel coefficients are estimated by correlating said received signal samples with said known symbols.

26. A receiver for decoding quantized and unquantized wanted data symbols from received signal samples, comprising:

a control adapted to process a group of currently received signal samples to determine a corresponding current set of unquantized wanted data symbols and an interfering waveform representative of a sum of other unwanted data symbols by subtracting an amount of a previously decoded set of quantized wanted symbols and a previously determined interfering waveform; and

a quantizer adapted to quantize said determined current set of unquantized wanted symbols to obtain corresponding quantized symbols.

27. The receiver of claim 26 further comprising a channel estimator for determining a set of channel coefficients characterizing multipath propagation.

28. The receiver of claim 27 further comprising a filter for filtering said received signal samples based on said channel coefficients.

29. The receiver of claim 28 wherein said filter comprises a time-reversed conjugate channel filter.

30. The receiver of claim 26 wherein said current set of unquantized wanted symbols includes only one wanted symbol.

31. The receiver of claim 30 wherein said control combines a pair of successively received signal samples in a first combining way to obtain said current unquantized symbol and combines the same pair of samples in a second combining way to obtain a value of said interfering waveform.

32. The receiver of claim 31 wherein said first and second combining ways are orthogonal combining ways.

33. The receiver of claim 31 wherein said first and second combining ways comprise multiplying said received signal sample pairs by a conjugate of a pair of complex spreading code values.

34. The receiver of claim 27 wherein said channel estimator determines said channel coefficients by correlating said received signal samples with known ones of said data symbols.

35. The receiver of claim 34 wherein said known symbols include previously decoded symbols.

36. A mobile terminal used in a mobile communications system decoding overlapping data symbols modulated with mutually orthogonal spreading codes in which some of said symbols are known a-priori, comprising:

a receiver receiving blocks of signal samples through a channel suffering from multipath propagation, a number of signal samples in a block being equal to a length of said orthogonal spreading codes;

a control subtracting from said signal samples intersymbol interference (ISI) related to previously decoded symbols and to said known symbols to produce corresponding blocks of ISI-compensated signal samples; and

a quantizer processing said ISI-compensated sample blocks to obtain a least-squares solution for the remaining, unknown data symbols each quantized to a nearest symbol in the alphabet of symbols with minimum mean-square quantizing error.

37. The mobile terminal of claim 36 wherein said subtracted intersymbol interference is based on channel coefficients that describe said multipath propagation.

38. The mobile terminal of claim 37 wherein said channel coefficients are estimated by correlating said received signal samples with said known symbols.

39. A base station used in a mobile communications system decoding overlapping data symbols modulated with mutually orthogonal spreading codes in which some of said symbols are known a-priori, comprising:

a receiver receiving blocks of signal samples through a channel suffering from multipath propagation, a number of signal samples in a block being equal to a length of said orthogonal spreading codes;

a control subtracting from said signal samples intersymbol interference (ISI) related to previously decoded symbols and to said known symbols to produce corresponding blocks of ISI-compensated signal samples; and

a quantizer processing said ISI-compensated sample blocks to obtain a least-squares solution for the remaining, unknown data symbols each quantized to a nearest symbol in the alphabet of symbols with minimum mean-square quantizing error.

40. The mobile terminal of claim 39 wherein said subtracted intersymbol interference is based on channel coefficients that describe said multipath propagation.

41. The mobile terminal of claim 40 wherein said channel coefficients are estimated by correlating said received signal samples with said known symbols.

42. A mobile communications system reducing interference between transmissions of wanted signals and unwanted interfering signals, comprising:

a receiver comprising a control adapted to process a group of currently received signal samples to determine a corresponding current set of unquantized wanted data symbols and an interfering waveform representative of a sum of other unwanted interfering data symbols by subtracting an amount of a previously decoded set of quantized wanted symbols and a previously determined interfering waveform; and a quantizer adapted to quantize said determined current set of unquantized wanted symbols to obtain corresponding quantized symbols.

43. The mobile communications system of claim 42 wherein said receiver further comprises a channel estimator for determining a set of channel coefficients characterizing multipath propagation.

44. The mobile communications system of claim 43 wherein said receiver further comprises a filter for filtering said received signal samples based on said channel coefficients.

45. The mobile communications system of claim 44 wherein said filter comprises a time-reversed conjugate channel filter.

46. The mobile communications system of claim 42 wherein said current set of unquantized wanted symbols includes only one wanted symbol.

47. The mobile communications system of claim 46 wherein said control combines a pair of successively received signal samples in a first combining way to obtain said current unquantized symbol and combines the same pair of samples in a second combining way to obtain a value of said interfering waveform.

48. The mobile communications system of claim 45 wherein said channel estimator determines said channel coefficients by correlating said received signal samples with known ones of said data symbols.

49. The mobile communications system of claim 48 wherein said known symbols include previously decoded symbols.

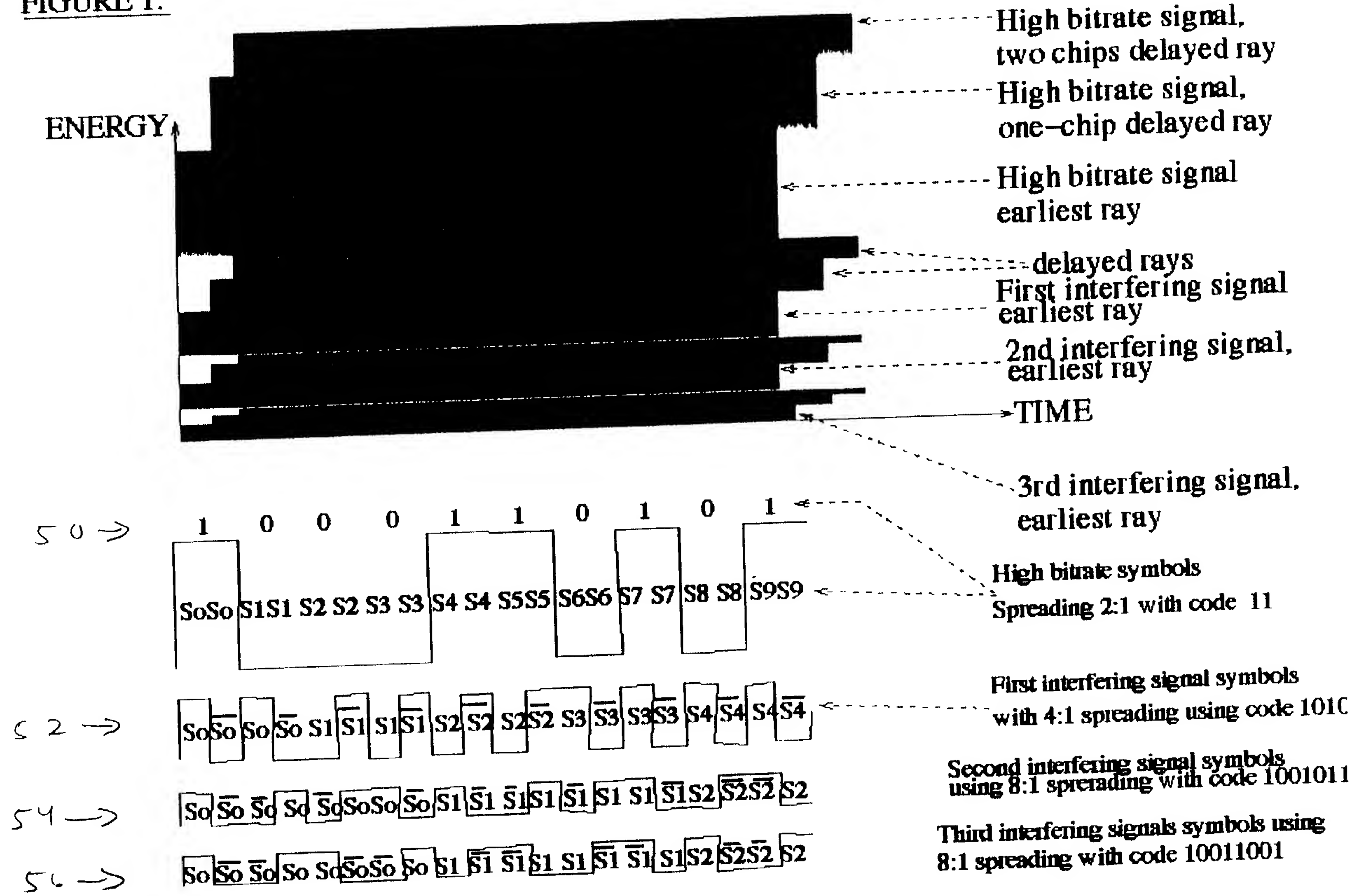
50. The mobile communications system of claim 42 wherein said receiver comprises a mobile terminal receiver.

51. The mobile communications system of claim 42 wherein said receiver comprises a base station receiver.

ABSTRACT OF THE INVENTION

A receiver decodes quantized and unquantized wanted data symbols from received signal samples. The receiver comprises a control adapted to process a group of currently received signal samples to determine a corresponding current set of unquantized wanted data symbols and an interfering waveform representative of a sum of other unwanted data symbols by subtracting an amount of a previously decoded set of quantized wanted symbols and a previously determined interfering waveform. A quantizer quantizes the determined current set of unquantized wanted symbols to obtain corresponding quantized symbols.

FIGURE 1:


ENERGY
TIME
High bitrate signal,
two chips delayed ray
High bitrate signal,
one–chip delayed ray
High bitrate signal
earliest ray
delayed rays
First interfering signal
earliest ray
2nd interfering signal,
earliest ray
3rd interfering signal,
earliest ray
50
1 0 0 0 1 1 0 1 0 1
SoSo S1S1 S2 S2 S3 S3 S4 S4 S5S5 S6S6 S7 S7 S8 S8 S9S9
High bitrate symbols
Spreading 2:1 with code 11
52
First interfering signal symbols
with 4:1 spreading using code 1010
54
Second interfering signal symbols
using 8:1 spreading with code 1001011
56
Third interfering signals symbols using
8:1 spreading with code 10011001

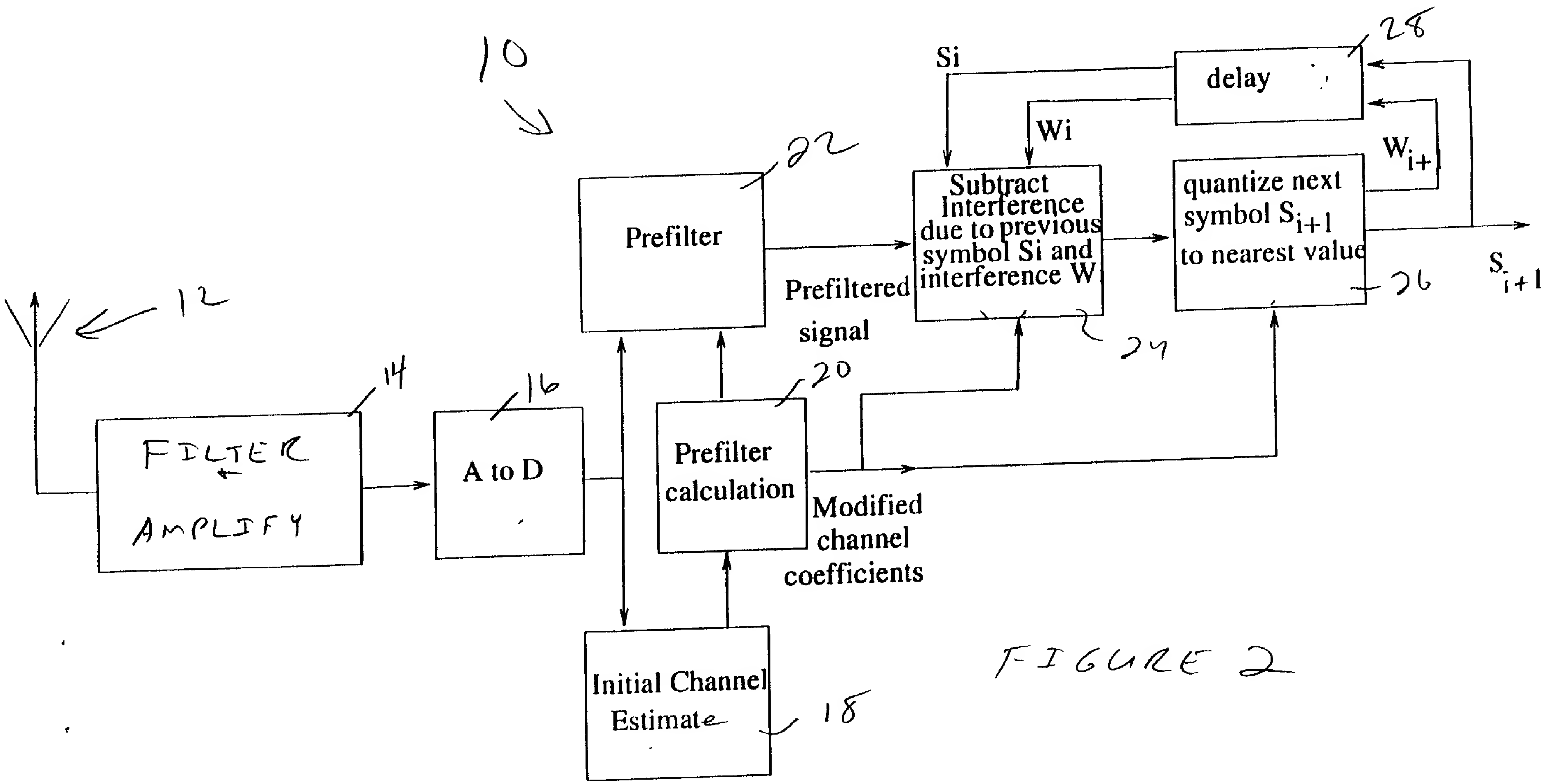
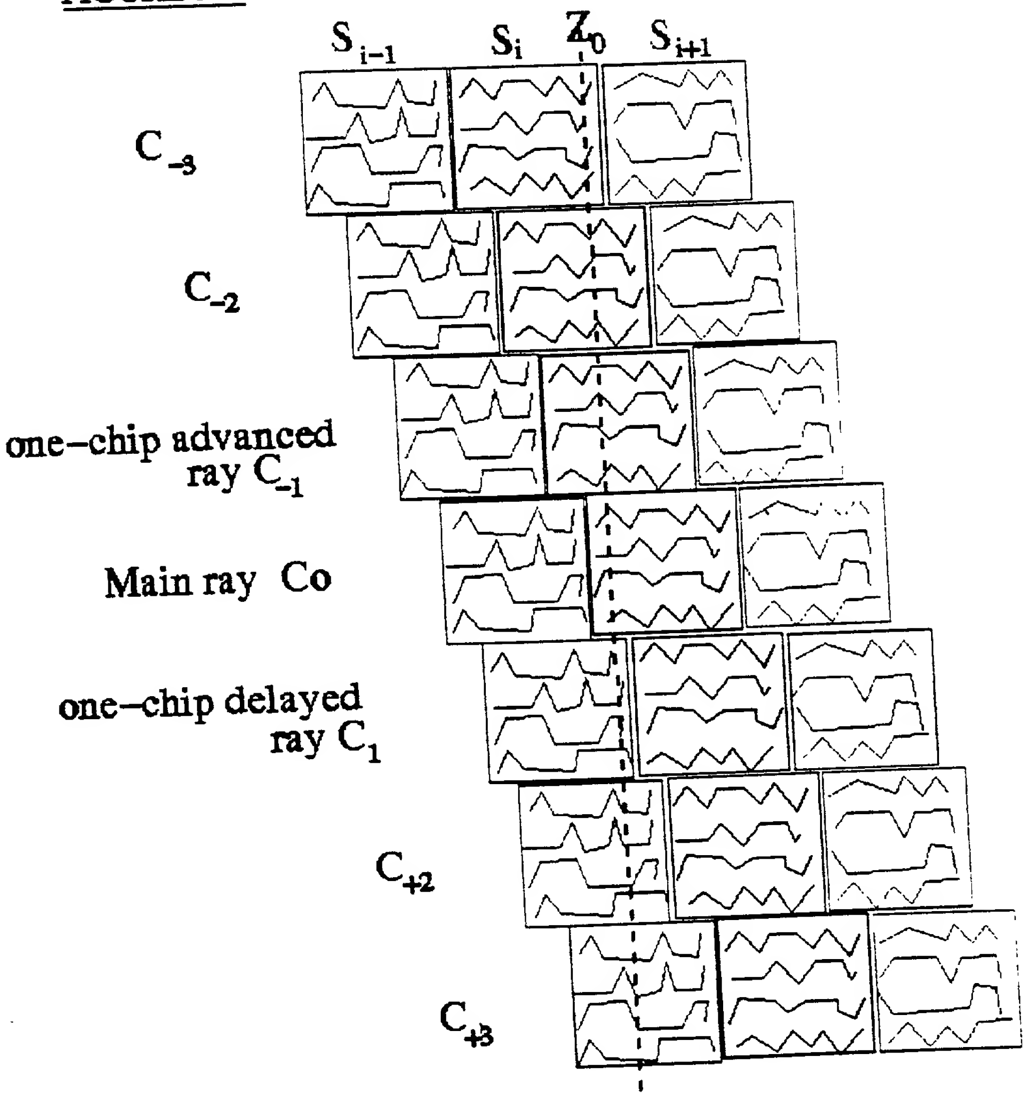

10
12
FILTER + AMPLIFY
14
A to D
16
Prefilter
22
Prefilter calculation
20
Initial Channel Estimate
18
Prefiltered signal
Modified channel coefficients
Si
Wi
Subtract Interference due to previous symbol Si and interference Wi
24
delay
28
quantize next symbol S_{i+1} to nearest value
26
W_{i+1}
S_{i+1}

FIGURE 2

FIGURE 3:



S_{i-1}
S_i
Z_0
S_{i+1}
C_{-3}
C_{-2}
one-chip advanced ray C_{-1}
Main ray Co
one-chip delayed ray C_1
C_{+2}
C_{+3}

DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name; that

I verily believe I am the original, first and sole inventor (if only one name is listed below) or a joint inventor (if plural inventors are named below) of the subject matter which is claimed and for which a patent is sought on the invention entitled: Method and Apparatus for Subtracting Multiple Rays of Multiple Interfering Received Signals, the specification of which:

☐ is attached hereto. ☐ was filed on ______
as Application Serial No. ______
and was amended on ______
(if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment specifically referred to above, and that I believe the named inventor(s) to be the original and first inventor(s) of the subject matter which is claimed and for which a patent is sought, and hereby acknowledge the duty to disclose information which is material to the patentability of the application in accordance with §1.56 (reprinted on the back) of Title 37 of the Code of Federal Regulations.

I also hereby state that no patent applications on this invention have previously been filed in countries foreign to the United States of America, except as follows:

COUNTRY	APPLICATION NUMBER	DATE FILED (day, month, year)	PRIORITY CLAIMED UNDER 35 U.S.C. 119
			yes no
			yes no
			yes no

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56 which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.)	(Filing Date)	(Status. patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status. patented, pending, abandoned)

I hereby appoint Richard S Phillips (Reg. No. 17,314), Wm. A VanSanten (Reg. No 22,810), Jeffrey L. Clark (Reg. No. 29,141), John S. Mortimer (Reg. No. 30,407), F. William McLaughlin (Reg. No. 32,273), and Dean A. Monco (Reg. No. 30,091), each registered to practice before the United States Patent and Trademark Office and practicing as the firm of **WOOD, PHILLIPS, VAN SANTEN, CLARK & MORTIMER, 500 WEST MADISON STREET, SUITE 3800, CHICAGO, ILLINOIS 60661 (Telephone 312-876-1800)**, and Charles L Moore, Jr (Reg. No 33,742), David G. Matthews (Reg. No 33,959), Kevin A. Sembrat (Reg. No. 36,673), Debra K Stephens (Reg. No. 38,211), David K. Purks (Reg. No. 40,133), Mark C Terrano (Reg. No. 40,200), Stephen A Calogero (Reg. No. 41,491), Herbert V Kerner (Reg No 42,721), Kermit D Lopez (Reg No 41,953), and Kenneth W Bolvin (Reg No 34,135), and my attorneys with full power of substitution and revocation, to prosecute this application, to make alterations or amendments therein, to receive the patent and to transact all business in the Patent and Trademark Office connected therewith, and direct that all correspondence be addressed to the firm All telephone inquiries may be directed to:

Dean A. Monco

§1.56 Duty to disclose information material to patentability.

(a) A patent by its very nature is affected with a public interest. The public interest is best served, and the most effective patent examination occurs when, at the time an application is being examined, the Office is aware of and evaluates the teachings of all information material to patentability. Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability as defined in this section. The duty to disclose information exists with respect to each pending claim until the claim is cancelled or withdrawn from consideration, or the application becomes abandoned. Information material to the patentability of a claim that is cancelled or withdrawn from consideration need not be submitted if the information is not material to the patentability of any claim remaining under consideration in the application. There is no duty to submit information which is not material to the patentability of any exists claim. The duty to disclose all information known to be material to patentability is deemed to be satisfied if all information known to be material to patentability of any claim issued in a patent was cited by the Office or submitted to the Office in the manner prescribed by §§ 1.97(b)-(d) and 1.98. However, no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct. The Office encourages applicants to carefully examine:

(1) prior art cited in search reports of a foreign patent office in a counterpart application, and

(2) the closest information over which individuals associated with the filing or prosecution of a patent application believe any pending claim patentability defines, to make sure that any material information contained therein is disclosed to the Office.

(b) Under this section, information is material to patentability when it is not cumulative to information already of record or being made of record in the application, and

(1) It establishes, by itself or in combination with other information, a prima facie case of unpatentability of a claim; or

(2) It refutes, or is inconsistent with, a position the applicant takes in

(i) Opposing an argument of unpatentability relied on by the Office, or

(ii) Asserting an argument of patentability.

A prima facie case of unpatentability is established when the information compels a conclusion that a claim is unpatentable under the preponderance of evidence, burden-of-proof standard, giving each term in the claim its broadest reasonable construction consistent with the specification, and before any consideration is given to evidence which may be submitted in an attempt to establish a contrary conclusion of patentability.

(c) Individuals associated with the filing or prosecution of a patent application within the meaning of this section are:

(1) Each inventor named in the application;
(2) Each attorney or agent who prepares or prosecutes the application; and
(3) Every other person who is substantively involved in the preparation or prosecution of the application and who is associated with the inventor, with the assignee or with anyone to whom there is an obligation to assign the application.

(d) Individuals other than the attorney, agent or inventor may comply with this section by disclosing information to the attorney, agent or inventor.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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